# Case Study - Designing An Advanced Visualization System for Geological Core Drilling Expeditions

**Yu-Chung Chen**
University of Illinois at Chicago
842, W. Taylor Street
Chicago, IL 60607 USA
julian@evl.uic.edu

**Sangyoon Lee**
University of Illinois at Chicago
842, W. Taylor Street
Chicago, IL 60607 USA
slee14@uic.edu

**HyeJung Hur**
University of Illinois at Chicago
842, W. Taylor Street
Chicago, IL 60607 USA
hhur2@uic.edu

**Jason Leigh**
University of Illinois at Chicago
842, W. Taylor Street
Chicago, IL 60607 USA
spiff@uic.edu

**Andrew Johnson**
University of Illinois at Chicago
842, W. Taylor Street
Chicago, IL 60607 USA
aej@evl.uic.edu

**Luc Renambot**
University of Illinois at Chicago
842, W. Taylor Street
Chicago, IL 60607 USA
luc@evl.uic.edu


*CHI 2010*, April 10–15, 2010, Atlanta, Georgia, USA.
ACM 978-1-60558-930-5/10/04.

## Abstract
We present the design and process of an interactive high-resolution visualization system for diverse and distributed real-world geological core drilling expeditions. The high domain knowledge barrier makes it difficult for a person who is outside this field to imagine the user experience, and the globally distributed core drilling community imposes more design constraints in space and time. In addition to activities proposed in prior literatures, we used the "immersive empathic design" approach of having a computer scientist trained as a junior core technician. Through in-situ observation and interview evaluations from on-going expeditions, we present the system and the lesson learned in the process. It makes the best use of precious co-located opportunities. It allows the developer to build up domain knowledge efficiently. It establishes a trust relationship between the developer and scientists. The system designed through this approach formed a sustainable foundation that was adapted in the following design iterations. This process allows the software developer to experience authentic user activities. The designed system is innovative and helps scientists solving real-world problems. This approach can be a useful example to HCI practitioners

who work with potential users or communities that share similar properties.


## Keywords
HCI, Visualization, Empathic Design

## ACM Classification Keywords
H.5.3 [Information Interfaces and Presentation]: Group and Organization Interfaces - Computer-supported cooperative work, Synchronous interaction, Collaborative computing

## General Terms
Design, Human Factors


## Introduction
It is hard to design a useful system. It is even harder to design a system for people who are in a different knowledge domain. Prior literatures and studies proposed participatory design [2] and user-centric design [3] to include potential users in the design process. Cognitive scientists embedded themselves in real-world working environments to study the "distributed cognition" [22]. However real-world users such as scientists may lack the motivation to have an outsider from other domains telling them what to do in their workflows. Researchers without prior domain background might have difficulties understanding the context. Empathic design [7] [8] was used in industry for commodity product design. Designers use activities such as biographies, scenarios, simulations, role-playing and social probes to try to step into users' shoes. While these practices are useful in designing commodity products, some of them may not be useful or even practical for scientific users, especially in the early stage of the design cycle. For example, the lack of background context might prevent the designer from fully understanding why a clastologist needs to count the number of rocks in a sediment core as soon as possible. The lack of mutual trust becomes another barrier during the design cycle.

We used the "immersive empathic design" approach of having the software developer trained as a junior core technician in the early stage of the development timeline. We believe this approach is more beneficial than merely conducting observation and dialogue activities from a third person perspective.

In the following sections we will first examine the problems faced by core-drilling geologists. We will show how geologists dealt with these problems and why they started seeking collaboration with computer scientists for a better solution.

## The Problems
"Geological cores are cylindrical bodies containing natural materials and sediments. They are recovered from the surface or the crust of the Earth. Just like tree rings, the composition and deposition layers of cores contain detailed records of the climatological and ecological changes on the Earth dating back millions of years" [1]. Different coring communities recover cores from lakes, oceans and Antarctica.

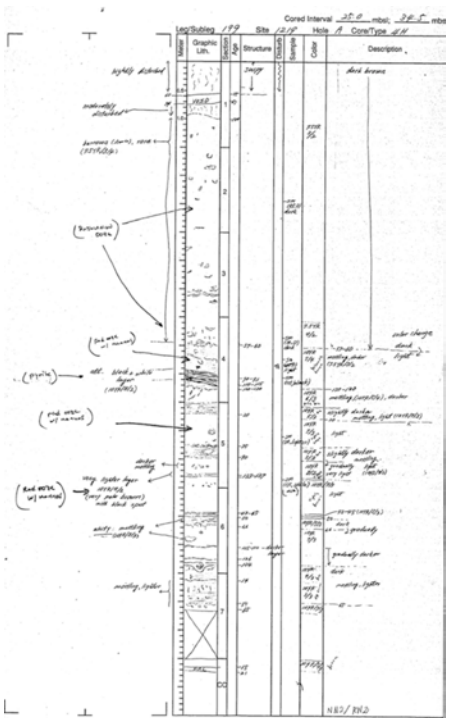

Figure 1 A hand-draw barrel sheet of the ocean drilling expedition [23].

In the past, scientists were using paper-based "barrel sheets" and pencils to document their interpretations during the expeditions (Figure 1). Since computers and digital imaging equipments were introduced to geophysics, scientists started acquiring a huge amount of numerical sensing data and core imagery. They used digital assets for printing barrel sheet templates. In order to generate a similar barrel sheet, they had to go through the following tedious steps: 1. Use image-processing software to scale down the raw image because the original image file is too large, 2. Use a spreadsheet and plotting program to generate numerical data plots, 3. Copy and paste these pieces into a desktop publishing program to generate a barrel sheet page. Commodity photo editing software does not allow them to easily navigate and visualize this huge amount of image data without interfering with their daily science workflow.

Moreover, geologists want to have a way to digitally input and keep track of the derived numeric data related to recovered records, and most importantly present this numeric data near the digital imagery. Several software systems have been developed in the past to solve these problems. Mike Ranger developed the proprietary AppleCore program for Ocean Drilling Program (ODP) in the 90's. It was a classic Mac OS 9 program for visual core description. The main purpose of the program was for publishing and it is not currently being updated or maintained. The Japan arm of International Ocean Drilling Program (IODP), the Center for Deep Earth Exploration (CDEX) developed J-CORES with a company. This software system was tightly coupled with a backend Oracle database and was written in pure Java. While it was used extensively in CDEX Chikyu expeditions, the tight backend and embedded logic dependency makes it less flexible and difficult for other geologists to adopt. The latest "Paleontological Stratigraphic Interval Construction and Analysis Tool" (PSICAT) was also developed as a Java based standalone graphical editing tool for creating and viewing core description lithological diagrams. None of these tools can handle the core imagery data when presented in its native resolution. Scientists must either scale down the imagery or load only one image at a time. The lack of deeper computer graphics expertise has been a roadblock to further advances.

Prior collaboration on the GeoWall project [10] and the need for modern visualization expertise brought geologists from the lake core facility to our visualization laboratory. In order to design a system that geologists can use in their daily work, we wanted to know why and how potential users might use the system. Through initial discussions with the scientists about the existing software systems, we found that these systems are either technology-wise incapable of processing a large amount of imagery data (those that were developed within domain) or there is a user-experience mismatch (those that were developed by outsourced companies).

How can we make use of current technology to build a system that allows scientists to access this large volume of digitized assets and facilitate geological research? What kind of new interfaces should be designed to leverage the unique affordances of these digital data?

Furthermore, by looking at the limitations of previous systems, we realized that we should not just implement a fast core imagery viewer using our graphics knowledge. We have to step into users' shoes in order to design a new system that can seamlessly blend into the scientists' daily work. In order to do this, we needed to know more about the actual workflow.

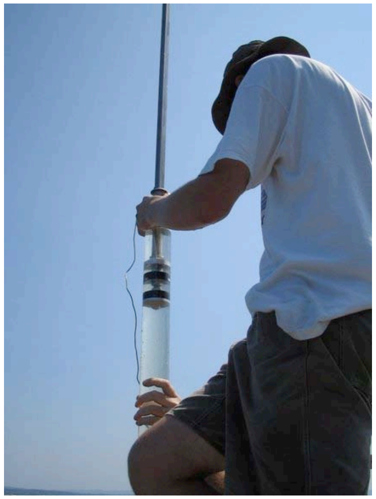

Figure 2 Core Drilling on Lake Pepin.

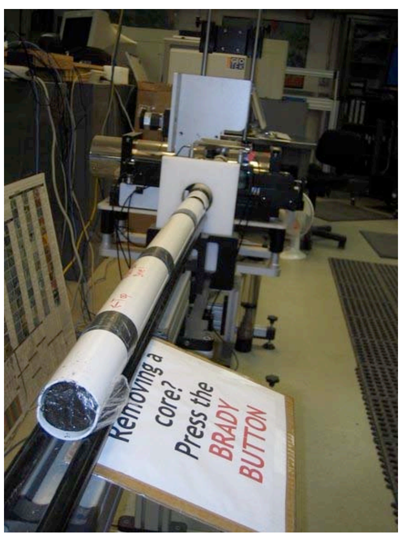


Figure 3 Multi-sensor core loggers.

## Method

*Situated in scientific workflow*

Just like any other scientific disciplines, core-drilling expedition involves: 1. Design experiment, 2. Conduct experiments, 3. Analyze results [17] and 4. Publication. For the modern expeditions and research, it gets even more complex. It might involve researchers distributed around the world. And the logistic cost for drilling vessel and personnel is enormous. We immersed into and evolved with the workflow with geologists to discover more details along the way and attempted afford users' needs in different phases.

In "first contact" meetings, we realized that core drilling involves a lot of hands-on work. And geologists like having people from the 'other side' becoming involved in their daily work. They can efficiently introduce a new person to their domain knowledge on the spot with context and hands-on experience. Sharing the hands-on experience and lingo breaks down initial social barriers which later shows benefits when introducing the newly developed system to other individuals and communities.

In the summer 2004, one of our computer science students in the development team joined expeditions in ocean and lake drillings. Because of the geographically distributed potential users, the student worked with specific coring communities and received training as a junior core technician from an early stage. In 2006, during a two-week training both in the field and in the laboratory, a student assisted in using piston tools to retrieve more than 10 meters of core samples from three locations in Lake Pepin, Minnesota. In the indoor laboratory work, he went through the processes including splitting the cores into "archive" and "working" halves, carefully smoothing the split core surface, and operating the high-resolution image scanning and multi-sensor core logging equipment to acquire digitized core data. He also attempted to do the initial visual core description as a real geologist.

*Generalized Workflow*

Through the immersive hands-on experience and understanding, we further generalized the detailed core expeditions workflow in different drilling communities. Once the cores are recovered they are spliced into roughly 1-meter sections for easy processing and transportation. Sections of cores are scanned through "multi-sensor core loggers" to measure physical properties including porosity, density, electrical resistivity and magnetic susceptibility. The cores are split into halves. In the past, scientists would study these split cores surfaces with observations and draw features and write comments on "barrel sheets" as shown in Figure 1. Now digital images of the split core surface will be taken and the sensor data will be plotted and printed on barrel sheets in tedious preprocessing steps described in the previous section. The core technician observes the physical core sections lay out on the examination table. He draws and writes down her interpretation on the barrel sheets. These paper assets serve as the initial visual core description records. They will later be used as the basis of further processing requests. After a core expedition finishes, the records will be stored with the physical core boxes in core repositories.

*Collaborative analysis and reflection through pitching*

After the hands-on training, we analyzed the audio/video clips collected and reflected on the experience, in order to re-gain the perspective away from users. The developer received the training would then put the visual artifacts on a large display wall [18]. He would "pitch" the story of being a core technician to other members according to his experience and visual artifacts shown on the display. Through the process, we found that there were additional issues in the workflow besides the functional issues described in the previous section.

- Assumptions from prior legacy practices. Geologists might unconsciously keep the final stage of the workflow in mind. They need to publish expedition report and papers. Geologists make heavy use of paper assets not only in description process but also during shifts. In participating the handoff process, we discover that geologists print out core descriptions on pages of paper. They will put the paper assets on the wall and making comments during handoff to keep track of research progress. The printed representation of the cores is an invaluable piece in the whole workflow. In attending geological conferences like American Geophysical Union Fall Meeting (always held in the week before Christmas), we found that the printed poster is the major representation of geological research result. You will be amazed to see so many people bringing poster tubes in the week before Christmas in San Francisco. Most existing tools and practices were designed toward such "final product". Bearing such assumption in mind, the unique affordances of the digital data were easily neglected. Even though scientists tried to utilize the digitalized assets, they did not make the best use of their affordances, which include feature-preserving representation in high-resolution and easy remote access.
- Observational constraints. The lighting conditions might affect core description and interpretation. For example, core description might be done right on the expedition site. Due to the time-shift and space constraints, the lighting conditions may not be optimal for core description, and that results in differences in the interpretations. The developer made inconsistent interpretations during the hands-on training because of this.
- Spatial and temporal constraints. The availability of physical cores could vary. In lake drilling, the cores will often arrive at the core laboratory weeks before the investigator can travel to "meet them". A similar and more extreme case was later found when we met with the Antarctica drilling community. In the case of Antarctica drilling, the cores will be boxed for shipping back to the repository once the expedition season is ended. The time to ship the cores could take another season. During the shipping period, scientists have no access to the physical cores.
- Computing capability constraints. For decades, stratigraphic records have been locked in core repositories around the world. Now, aided by advanced equipment such as high-resolution color line-scanners and multi-sensor data loggers, core data can be digitized to create a large amount of high-precision digital images and numerical data. Scientists want to use these digitized core assets to make the data more accessible to researchers, but the size of the data becomes an issue. The amount of data can be estimated from the numerical sensor dataset and image sizes. For 1,000 meters of cores, the digitized images take up much more space than the sensor data. A digital line-scan camera can produce images from 254 to 1000 dots-per-inch (DPI) in resolution. Consider

1,000 meters of split cores using a 254 DPI configuration. The total image size can be calculated to be 10,000,000 x 900 pixels in RGB color space, which is about 27GB of raw image data. There are about 10km of cores archived in LRC, which is about 270GB of imagery. The cores recovered in the Antarctica McMurdo Ice Shelf expedition take up roughly 30GB for a single hole. The digitized ocean drilling core data takes nearly 9 TB. Scientists cannot examine this data easily using existing tools. Often times due to the frustration, they will fall back to much-lower resolution images or even the older barrel sheets.

## System Design

Aside from the requirements to solve these issues, there are constraints that the developer found in interfacing with scientists during the training period.

- Geologists emphasize working with physical cores. Similar to domains like biology and medicine, core-drilling geologists rely heavily on physical interactions with the recovered samples, especially in the initial core description phrase. Out in the field, you can see geologists getting their hands dirty in the mud to take samples. In the laboratory, they will lay all the recovered core sections on an already crowded examination table and use a magnifying glass to look at the details of the split core surfaces.
- Information technology (IT) resource support for mid-size to individual scientists is limited. Geologists coming to use LacCore facility usually do not have the luxury of having dedicated IT staff support.
- Because of the physical space constraints, geologists must mentally keep track of the spatial relationship of core sections for visual core description.

Figure 4 CoreWall setups with tiled displays.

For example, 30 meters of cores might be recovered in different drill sites during one expedition. After splitting it into 1-meter sections, the worktable is still not big enough to hold all sections arranged in their original spatial relationship. Geologists can only work on few sections at a time and constantly have to mentally keep track of which section is on the table.

We proposed the CoreWall system, which includes a single workstation with multiple large LCD displays as shown in Figure 4. For the constraints, the system supports configurable multiple LCD visualization output. The displays can be arranged horizontally just like how the physical cores being layout on the table. It provides a familiar experience, as if geologists are examining physical cores. The use of a single machine eases the maintenance burden on the core drilling workflow that already suffers from a lack of IT support while still giving enough screen space for individual work and small group discussions. Because of the unique affordances of digitalized imagery, the spatial relationship of sections of cores can be maintained in the CoreWall visualization output. This not only eases the extra mental load but also stimulates more research ideas, said scientists in interviews.

For the problems and issues described in previous sections, LCD display technology allows for easy color calibration that provides a unified environment for core interpretation. Corelyzer is the software application of the CoreWall suite. Its design focuses on bridging the gap between geologists and the huge amount of digital core data. It is implemented with multi-level image texture paging system that provides scientists with highly interactive browsing and manipulation of thousands of meters of geological cores. Scientists can

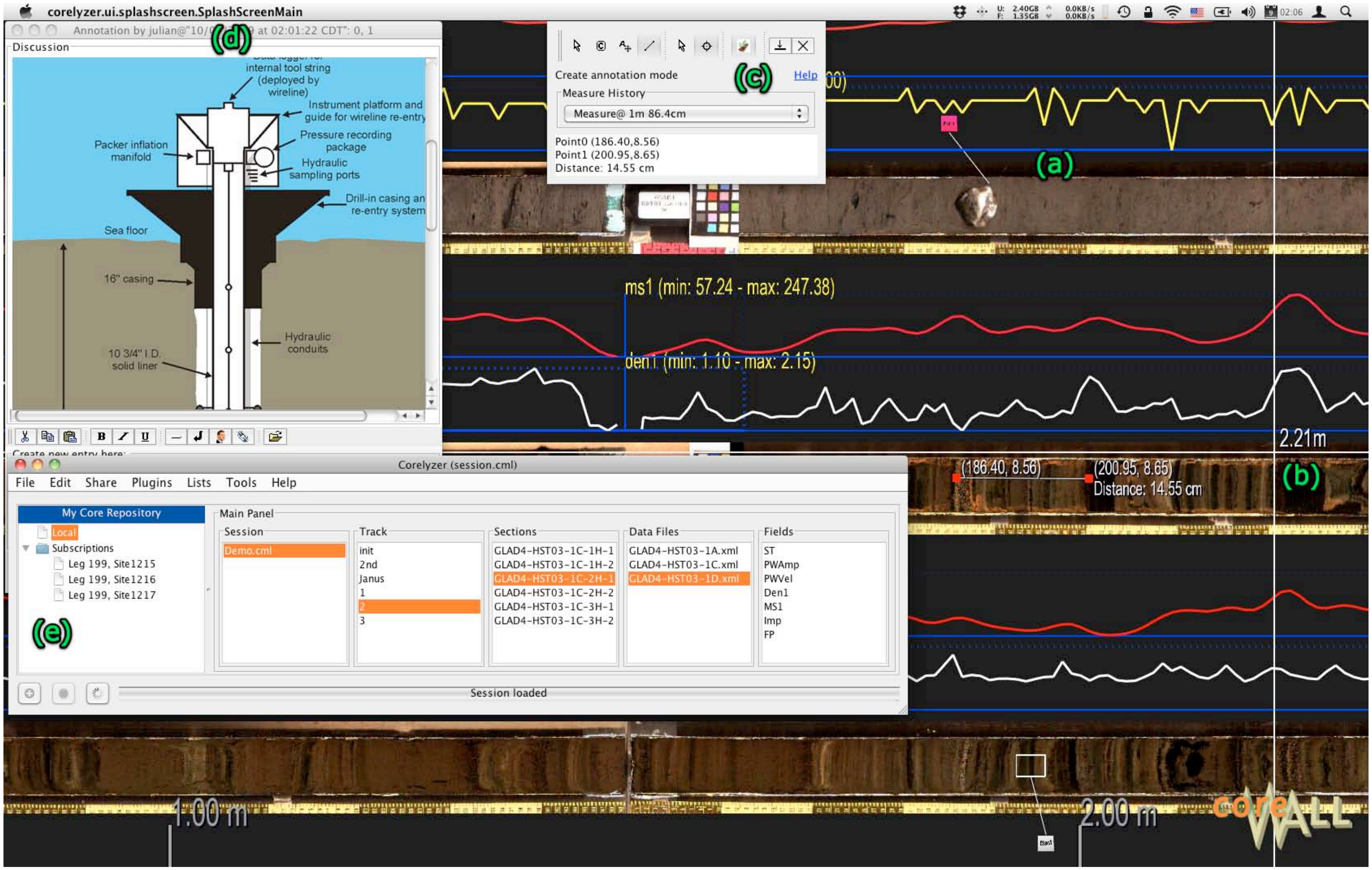


Figure 5 User interface screenshot. (a) The main core data context will be shown in the backdrop co-registered in depth. (b) A crosshair with current depth information is shown lets users easily identify the location of the cursor. (c) Common toolbox will float from one display to another (in the upper center of the display) with the crosshair. (d) User interface elements like popup dialog and window will be positioned close to the crosshair cursor when it first appears on the screen. (e) The iTunes-like interface allows the users to subscribe to "CoreCast" and retrieve core data from different sources.

easily pan the core images with familiar drag-and-drop mouse gestures and zoom to the finest detail with mouse scroll wheel. It presents all the related information co-registered with physical depth information on a screen that is larger than the physical cores. The resulting juxtaposed digital "mashup" can be packaged and distributed to interested colleagues for further collaboration.

The hardware design also affected the design of software user interface. (Figure 5)

1. Since the tiled display is used for presenting high-resolution visualization, the display bezels are taken into account when generating visualization output in order to reduce the interpretation interference [20].

2. Because the physical visualization is large, the system should keep track of the user's current attention point. Often used user interface elements should be easily accessed. The most common toolbox will follow mouse cursor from one display to another. User interface elements like dialogs and status notifications should popup close to attention focus area. This is absent in most of modern operating systems' user interface design for the multi-monitors setups [19].

3. Scientists can easily navigate the through all core data with familiar dragging mouse gestures and smoothly switching from overview to micron level details with mouse scroll wheel.

4. The software has a built-in multi-level image texture paging system. It can visualize thousands of meters of geological core data depth-registered and still maintain fluid interactivity.

5. An annotation system was also designed to support creating juxtaposed digital "mash-up". The "mash-up" can be packaged and distributed to interested colleagues to support synchronized or asynchronous remote collaboration.

Figure 6 Core description simulations

The CoreWall system becomes a piece of equipment for initial core description in the core laboratory. It allows geologists and even drillers to get immediate feedback from the data to make on-the-spot sampling or drilling decisions during a coring expedition. That is something that they could not do before.

## Polar Drilling Deployment

After we designed the CoreWall for LacCore scientists, we wanted to see if such a setup developed through an "immersive empathic design" approach could also be beneficial and sustainable in a different core drilling community.

"Antarctic geological drilling is a multinational collaboration comprised of more than 200 scientists, students and educators from five nations to recover stratigraphic records from the Antarctic margin" [11]. In the summers of 2006 and 2007, ANDRILL drilled in the McMurdo Ice Shelf and Southern McMurdo Sound. Each season ANDRILL planned to recover more than 1,000 meters of cores that can be dated back to 40 million year ago. Scientists are interested in cores from the Antarctica because the whole Antarctica has long been covered with ice and the continent below the ice could be one of the most un-disrupted areas that contain the answers to environmental changes, paleo-glacial activity and paleo-climatology.

In May 2006 we presented the CoreWall system to other core drilling communities at the geological workshop held at the Jointed Oceanographic Institute

Figure 7 Dr. Franco Talarico and his clast drawing sheets. Photo taken by Josh Reed, ANDRILL

office in Washington D.C. Even the majority of the workshop participants were geologists, but the developer could easily immerse and join the discussion. We found that sharing the hands-on coring experience was one major reason. The experience was referenced (as discussion context) multiple times during the introduction among communities in the workshop.

There were only few months before ANDRILL first set off. We conducted interviews with the staff scientist during the meeting. We wanted to know more specific user needs and the workplace scenario in order to seamlessly integrate the system into their workflow in Antarctica.

We demonstrated the system and discussed the planned ANDRILL workflow. One of the conclusions was that the CoreWall system should minimally interfere with the other existing scientific activities and practices. We agreed that CoreWall could be used in several places without causing too many adverse impacts:

- In the core description team: A CoreWall workstation will be used in the core description process to assist the investigation of specific sections of the core acting as a digital microscope.
- In the morning progress meeting and public discussion area: During the morning meeting, a large tiled display CoreWall system will be placed in a common area to encourage and facilitate group discussions.
- In each member's laptop: Project members who are interested in the digitized dataset can access the data freely via wireless network. They can download the dataset to their personal laptop and visualize it using CoreWall for their own offline individual research.

Based on the staff scientist's interview suggestions, we further enhanced the annotation functionality similar to previous work in [5] and persistent data and knowledge distribution system like [4]. The system was verified in the pre-drilling meeting, just weeks before the real deployment. During this meeting we used the "simulation" technique along with sedimentologists to simulate the workflow as if they were in the Antarctica. The reason for the simulation before first deployment was that this group of scientists is going to be the major user of the system. We wanted to make sure they could share similar user experience as the LacCore scientists on the task of visual core description. We conjectured that once we provided easy access to high-resolution datasets, the members in the ANDRILL expedition team might want to utilize the annotation feature to share their ideas and comments right on top of the context of core imagery.

In order to properly support the expedition under that extreme spatial constraint (geologists in the Antarctica), we adapted the "embedded proxy" approach. While the CoreWall development team remained in North America, there was a computer scientist working with ANDRILL scientists down in the Antarctica during the expedition season. He worked with the scientists in the same location and he acted as communication proxy for immediate support.

### User Feedback

The CoreWall systems were used during the three months duration of the first ANDRILL expedition in late 2006 to early 2007. During this period, we received the

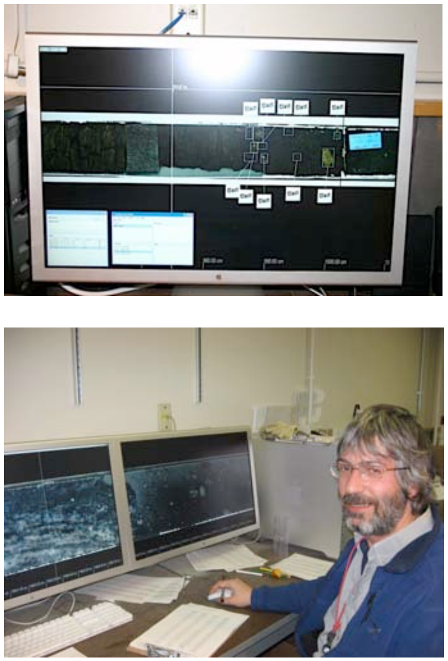

Figure 8 Dr. Franco Talarico in front of the CoreWall setup in Crary Lab in U.S. McMurdo station, Antarctica.

Photos taken by Ken Manhoff (above) and Betty Trummel (below), Husmann Elementary School, Crystal Lake, Illinois

following messages (among others) sent from McMurdo station in Antarctica.

*"… Corelyzer gets quite a bit of use especially during the night. The sedimentoligists and the clastologist use it a lot when they are logging the core. It also gets a fair amount of use during the morning when people come in and want to see the upcoming core." Josh Reed, ANDRILL IT Manager, November 15, 2006*

*"… FYI Corelyzer is being utilized extensively. People are very impressed with both Corelyzer and PSICAT. All is working rather well." Dr. Richard Levy, ANDRILL Staff Scientist, November 22, 2006*

*"… Corelyzer is awesome. Only rave reviews from users down here. Some suggestions to improve (added capabilities) but it really has been used a lot on a daily basis. ... People are very happy with Corelyzer." Dr. Richard Levy, ANDRILL Staff Scientist, December 12, 2006*

While the feedback from users was positive throughout the season, we found that the annotation function was not fully utilized as we expected. After further investigation, we found that we overlooked two important factors. The first reason was that there were other systems that users used during the expedition sharing similar annotation functions, and scientists still tended to exchange ideas either with face-to-face conversation or through emails. The second reason was more related to the organizational composition of the expedition team. The project included not only core geologist but also schoolteachers. During the expedition period, only a small portion of the members is data "publishers". Most of the members in the team are data "subscribers". Major data propagation mostly happened in one direction. This might be due to: 1. This is the first of its kind expedition for ANDRILL. There was little prior reference experience. 2. We used different approaches when targeting an existing system to a different group. Unlike embedding a developer with the LacCore scientists, our big picture and detailed workflow knowledge about ANDRILL was established based solely on interview observations.

However, there one specific usage of the CoreWall caught our attention. We found that Dr. Franco Talarico from the University of Siena, Italy used the system extensively. He is the clastologist in the ANDRILL project. Clasts are rock fragments or grains resulting from the breakdown of larger rocks. A clast can scale from 2-4 mm to more than 256 mm. They are both time and labor intensive to identify from a core's physical scale. "In all sediments clasts are essential tool to reconstruct the provenance of debris supplied to a subsiding basin through erosion and transport processes in nearby topographic heights", said Dr. Talarico. In the past, in order to calculate the clasts distribution, Dr. Talarico had to look at the physical cores and then hand-draw them on pieces of paper meter by meter in order to properly classify and count them in terms of size, shape, and lithology. In the 2006 season Dr. Talarico used CoreWall to zoom in and draw the same diagrams on paper from the core images as soon as they were available. When the actual core was in the laboratory for description, he verified what he had drawn with it. The capabilities of the CoreWall allowed him to scale high-resolution core images to fill display space with full details. That made his work easier. At the end of the 2006 expedition, more than 1,200 meters of cores were recovered. Laid end-to-end,

Figure 9 CoreWall systems used in the next generation US. JOIDES Resolution scientific drilling vessel.

Dr. Talarico's hand drawings stretch out of his office and down the hallway as shown in Figure 7.

In the 2007 season, we enhanced the CoreWall for Dr. Franco based on the annotation system. Instead of a "freeform" annotation provided for idea exchange and discussion, we proposed a "structured" annotation so users could easily input property values pairs based on a pre-defined dictionary. The CoreWall allowed him to examine and circle clasts on the high-resolution core images directly as annotations. The system would mark, record and generate a quality spreadsheet report, which saved not only Dr. Franco's time, mental loading and space. The structured style annotation system could be potentially a preferable interface to provide quality control over user-generated contents in scientific applications.

Because of this usefulness, in the second season, ANDRILL increased the number of CoreWall workstations from two to six. Dr. Franco received a dedicate workstation for his research and there was even one CoreWall setup at the drill site to support on-the-spot drilling decisions.

In 2009, the system was further integrated with Correlator, the stratigraphy correlation tool. The integrated system was deployed on the renovated "US. JOIDES Resolution" scientific drilling vessel. The system could make use of not only numerical sensing data but also the high-resolution images. It allowed geologists intuitively analyzing and correlating adjacent holes and constructing a composite depth scale for each drilling site [21]. The major improvements are summarized in the table below.

| Function | Usage | Importance | Application |
|---|---|---|---|
| Tiled-screen setup | Side-by-side as the core table | Similar core description setup | Initial LacCore adoption |
| Level-of-Detail, out-of-core image rendering | Scale to massive datasets | Smooth user interactions | LacCore and ANDRILL prototype |
| Annotation system | Distributed rich media core annotations | Distributed core annotation and sharing | ANDRILL 2006 |
| Customizable annotations | Task-specific annotations | Assist users accomplish tasks easily | ANDRILL 2007 |
| CoreCast feed management | Data source connectivity and management | More flexibility and reaching for more communities | ANDRILL 2007 & accessing IODP legacy data |
| Visual core correlation | Core segment correlation | Restore more precise depth/age scale | IODP JODIES Resolution expeditions |

Table 1 CoreWall improvements summary

**Evidence**

- Scientists were using it. Aside from the feedback such as those from ANDRILL users described above, the ANDRILL staff scientist also said that he felt so proud that each of the participating countries left Antarctica with a detailed copy of all digitized core data and the CoreWall software. This allowed them to carry on their work. That was never done before. In the first post-drilling meeting held in Florida State University, more than 20 members were still using the CoreWall software on their laptops and wanted to setup CoreWall stations in their home institutions.
- Scientists started requesting more high-resolution data. Scientists started to scan the cores at the highest resolution possible. Before the CoreWall system, they did not have a tool capable of visualizing all expedition data at their native resolution. Hence they had to compromise and reduce the imagery to lower quality that limited the value of the data. Now with CoreWall, they wanted to capture all the details. In the second season of ANDRILL expeditions, they even went to the manufacturer of the digital line scanner to make sure they squeezed out all the resolution from the equipment.
- Even better than the real thing. At the beginning of the process, we computer scientists conjectured that it might be challenging to turn scientists' observation habits around from physical and tangible to digital. In ANDRILL, while scientists were still excited when seeing the physical cores just recovered from the drill site, during group activities the high-resolution large display actually attracted people leaning over and stimulated more discussion and idea exchanges. In the case of lake cores, one scientist even reflected the high-resolution digital photos were actually better than the physical cores for certain work. The reason is that lake sediment cores contain more water, and the structure features might be oxidized and damaged over time once the cores were recovered. As described earlier, it might be weeks later when the investigator travels to meet the cores. By that time the structure features on the surface of the cores can be damaged forever. Being able to access the high-resolution imagery right after the cores are acquired allows the remote investigator to make immediate judgments early. The curator can also do meaningful sampling operations based on the remote investigator's request.

While the immersive empathic design approach was not employed extensively during the whole deployment period, the major functionality of CoreWall was designed using this approach in the earlier LacCore phrase. The foundation of the CoreWall work was sustained and generated positive responses in the ANDRILL deployment. These comments and feedback suggest that the system designed using this methodology was really utilized by the scientists. We found that the early immersive experience really brought the software designer into the domain community. This efficiently lowered the knowledge barrier in a relative short time. It also lowered the social barrier to enter the domain that was even more significant for introducing the system to other coring communities. Such an invisible trust relationship building is hard to achieve with other techniques.

However, this does not mean that scientists can do all their work with the digitized data. They still need to conduct physical smear slide sampling and chemical analysis etc. The CoreWall system acts as a piece of equipment in the laboratory just like an electronic microscope. It empowered the scientists utilizing the full affordances of digital assets. As a scientist pointed out, “it can do a lot of important components in the research workflows well.” With the easy distribution digital assets, scientists are now traveling less to distant core repositories.

## Discussion

There are challenges designing and deploying an interactive system to a real-world working environment. We found that while different techniques were used in the design and development cycles due to spatial and temporal constraints, the “immersive empathic design” approach used at the early stage benefitted most in later adoptions among individuals and large expedition communities. Some evidences even showed changes in the scientists’ workflows.

As described in the reflection after immersive hands-on training section, users and designers might unconsciously make assumptions based on prior legacy practices . Geologists need to publish expedition report or papers eventually. This prior mindset affects the design of existing tools. The user interaction requirements and data affordances were easily overlooked. The proposed approach sparks innovations within the workplace with emphasis the value of users and the artifacts.

The information distribution pattern will affect how users use a system and interface design. The information flow pattern is different in different communities. The LacCore structure is more bottom-up. Individual scientists work on their own expedition projects and ship the recovered cores to the LacCore laboratory to do digital acquiring and initial core description. These scientists do not have their own facilities to do all the laboratory work but they are more agile and flexible and willing to experiment with new ideas. In contrast the integrated ocean drilling program maintains a top-down hierarchy. All database model, workflows and tools are designed and developed in-house. This provides a well-defined system for its users to follow, but at the same time it lacks flexibility. The Antarctica drilling project lies somewhere in-between. As mentioned earlier, it is the first expedition of its kind in recent years. Workflows and practices are gradually being established as the project progresses. The adaption of the annotation system during the Antarctica drilling expedition is one example that designer and developer should consider such implicit differences.

Scientists want the freedom to choose what tools to use. Often they might not know of advances in other fields that could fundamentally change the way they work. When a tool does not fit their needs, they will create workarounds by mixing tools in a way that is not anticipated. We found that the shared hands-on experience in the early cycle not only helps early adoption but also the introduction to other communities. It was almost like a “ritual” of entering a new society. Passing the “ritual” created some invisible bond. The hands-on working experience was referred frequently during discussion in the workshops and conferences.

Different science domain users might have different degree of the acceptance to new technologies. For example, digital imaging analysis software tools are common in biology research. We found that in the early stage for each coring group, there were always geologists skeptical about the authenticity and usefulness of electronic core imagery. They would prefer to observe physical cores even though the digital image is perceptually better. A well-designed system that values users' needs could tackle such bias and utilize the system in proper process in the workflow.

## Conclusion

In this paper, we described a case study of designing an interactive high-resolution visualization system for geologists solving real-world problems using immersive empathic design process. The system was well received and considered useful in real-world expedition deployments evidenced by presented analysis on the observations and interviews. The method and lessons learned could be beneficial to future HCI practitioners when the potential users of the system are within domains sharing similar qualities such as high knowledge domain, geographically distributed users and remote collaborations.

## Acknowledgements

We would like to thank Dr. Emi Ito, Paul Morin, Anders Noren, Amy Myrbo and Dr. Mark Shapley from the National Lacustrine Core Repository, University of Minnesota, providing the great opportunity for the core drilling experience and technician training. We also want to thank Dr. Frank Rack, Dr. Richard Levy, Dr. Franco Talarico and Mr. Josh Reed of the Antarctica Drilling project for their great support and insightful input.

Corelyzer is a part of the CoreWall project and is being developed by the University of Illinois at Chicago's Electronic Visualization Laboratory. Funding provided by the National Science Foundation to the University of Illinois at Chicago, award OCE-0602117.

## References

[1] Cohen, Andrew S., Paleolimnology: The History and Evolution of Lake Systems. Cary, NC, USA. Oxford University Press, Incorporated, 2003

[2] Michael J. Muller, sarah Kuhn, Participatory design, Communications of the ACM, June 1993

[3] Vredenburg, K., Mao, J., Smith, P. W., and Carey, T. 2002. A survey of user-centered design practice. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems

[4] Tollinger, I., McCurdy, M., Vera, A., Tollinger, P., "Collaborative Knowledge Management Supporting Mars Mission Scientists," Proceedings of CSCW 2004, pp 29-38

[5] Olsen Jr., D; Taufer, T; Fails,J.A.; "ScreenCrayons: Annotating Anything", ACM UIST 2004 Conference Proceedings, pp 165 - 174.

[6] Irestig, M., Eriksson, H., Timpka, T., "The impact of participation in information system design: a comparison of contextual placements," Proceedings of the eighth conference on Participatory design, pp. 102-111

[7] Leonard, Dorothy and Jeffrey F. Rayport, "Spark Innovation Through Empathic Design," Boston: Harvard Business Review Nov-Dec 1997

[8] Wright, Peter, McCarthy, John, "Empathy and experience in HCI", Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems 2008

[9] Lin, A., Dai, L., Ung, K., Peltier, S., Ellisman, M., "The Telescience Project: Application to Middleware Interaction Components", $18^{th}$ IEEE Symposium on Computer-Based Medical Systems, pp.543-548

[10] Johnson, A., Leigh, J., Morin, P., Van Keken, P., "GeoWall: Stereoscopic Visualization for Geoscience

Research and Education," Computer Graphics and Applications, IEEE 2006 vol. 26(6) pp. 10 -14

[11] Antarctica Geological Drilling, http://andrill.org/

[12] J-CORES: http://sio7.jamstec.go.jp/j-cores/

[13] Buchenau, M. and Suri J.F., "Experience prototyping", Proc. DIS 2000, ACM Press (2000), 424-433

[14] Blythe, M. Monk, A., and Park, J. "Technology biographies: Field study techniques for home use product development." Proceeding of CHI'02 (Extended Abstracts), ACM Press 2002, 658-659

[15] Mattelmaki, T. and Battarbee, K. "Empathy Probes." Proceeding of Participatory Design Conferences 2002, CPSR Palo Alto (2002), pp.266-271

[16] Olson, G.M., & Olson, J.S. "Distance matters", Human-Computer Interaction, 2000, 15, 139-179

[17] Bose, R., Frew, J. "Lineage retrieval for scientific data processing: a survey", ACM Computing Surveys, Volume 37, Issue 1, 2005

[18] Renambot, L., Jeong, B., Jagodic, R., Johnson, A., Leigh, J., Aguilera, J. "Collaborative Visualization using High-Resolution Tiled Displays", CHI06 Workshop on Information Visualization and Interaction Techniques for Collaboration Across Multiple Displays, 2006

[19] Czerwinski, M., Robertson, G., Meyers, B., Smith, G., Robbins, D., and Tan, D, "Large display research overview", In CHI '06 Extended Abstracts on Human Factors in Computing Systems

[20] Mackinlay, J.D.; Heer, J. "Wideband displays: mitigating multiple monitor seams," ACM International Conference on Human Factors in Computing Systems (CHI 2004); 2004 April 24-29; Vienna, Austria

[21] Wolf, L., Higgins, S. "New Software Aids Geoscientists Aboard Scientific Ocean Drilling Expeditions", Science 360, National Science Foundation, 2009 April 30

[22] Edwin Hutchins, "Cognition in the wild", The MIT Press 1996

[23] Ocean Drilling Program, Janus Web Database: http://www-odp.tamu.edu/database/